WHAT IS OPERATIONAL RESEARCH?[1]

BY

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IN Britain Operational Research has been for many years a University subject, notably at London and Birmingham. We have also been influenced by American practice, dominantly so by Ackoff's school at the Case Institute. But, in this country, it is only in Lancaster that O.R. has, for the first time, achieved professorial status and a department of its own. Consequently, I am aware that I must establish the *bona fides* of my own discipline, as something worthy of development at University level. I accept this challenge with pleasure.

But what is Operational Research? It is in a phrase, the attack of modern science on the consequences of decisions in complex situations. You may ask why this should be either difficult or worthy of academic research.

The development of power-generating equipment and machine tools, which was the cause of the Industrial Revolution, has led to an increase in the viable size of businesses and this continues. This, in its turn, has led to the virtual disappearance of the single owner/manager who controlled the small concerns which once made up the bulk of British industry. The single owner has been replaced increasingly by a group of creditors or shareholders. The single manager also began to disappear, since one man could no longer manage everything, and there began the segmentation of the management task itself. The primary segmentation was to delegate the activities of controlling Personnel, Production, Purchasing, Marketing and Finance and so on to separate people. As companies continued to grow and expand, these senior officials had to delegate part of their responsibilities, and those appointed very soon had to delegate and sub-divide their own responsibilities. Hence there developed the segmentation of the management task down into extremely specialized responsibilities. As companies built new factories, new organizations, so this intricate management set-up was replicated in different locations.

We have experienced, over the last hundred years, not only rapid growth in the size and complexity of companies but also an explosive growth and segmentation of science itself. The growth of company size has inevitably led to an increase in the complexity of the decisions facing the industrial executive. But the development of new processes and new products which science and technology has made possible, has also made the task of decision-

[1] Based on an inaugural lecture at the University of Lancaster 12th May 1965.

making much more difficult. Operational Research is the attempt of the scientist to help with complex decision-making whether in industry, in government, in local administration or in military organizations. For the complexity of the decisions the scientist himself through his discoveries has been largely responsible.

It is not now possible for the manager to proceed by trial and error. (From here on I use the word manager to describe a person responsible for taking significant decisions whether in business, military, industry, commerce, government or in any other organization). Trial and error is not a possible way of learning in these situations for two reasons. The first simply stems from the time factor. We cannot, in large complex situations, keep back-tracking and trying different policies again and again, and from this gradually see emerge a feel for those policies which best match with the organization's objectives. By the time trial and error had given us a solution, the outside world would have changed so much that the solution would no longer be valid, we would have solved a problem that no longer existed. The second reason is that what is at stake in the large complex issues are large and complex results. We are faced therefore, not so much with trial and error but with trial and catastrophe. If, therefore, the method of trial and error fails (and this is a method which, when prosecuted under proper controlled conditions, is the normal method of statistical experimentation) how else can a scientist hope to be of use and form conclusions based on concrete evidence?

Model Building

We must, at this point, remember that not all scientists can experiment directly with the phenomena they are studying and, even when they can, they have to learn to generalize from a number of direct observations and to formulate a hypothesis which brings together in a common law all that has so far been observed. 'London Bridge is falling down' is an example of a particular experiment by an engineer which failed, but nowadays the engineer does not have to experiment with building bridges and check how many of them fall down; he builds a model. But, in reducing a large structure to scale, the scaling factors apply in different ways and so he cannot experiment with a bridge by making a physical model bridge. His model is diagrammatic. Through force diagrams, he is able to see the way in which different structures are likely to react under different conditions of load. Force diagrams consists of a series of thin lines drawn on a piece of paper. No-one imagines that in real life the forces go through the structure of the bridge along thin, spindly lines. In real life the forces are transmitted by the action and interaction of millions of molecules, one upon the other. At the stroke of a pencil the engineer removes a whole set of the variabilities

of the real life situation and replaces them by a stylized representation within the terms of which he can experiment and get answers accurate enough for his purpose.

Models are endemic in science. Keynes produced a model of the economy. Newton produced a model of the universe, a few equations of algebra which brought into the terms of one statement the whole of the universe from the movement of the stars in the furthest heavens, to the collision of two balls on a billiard table. All models of this form are ways of generalizing observation and experience and they enable us to interpolate for missing values in between the situations we have observed. They also give us a way of extrapolating beyond what we have observed, into the unknown.

It is natural that scientists who try to study the consequencies of decisions in complex situations should also seek to do so by means of a model. A model, as used in science, is a conscious recognition of the breakdown of language. We are familiar with the difficulty of using language to convey our feelings in even ordinary everyday situations. Because ordinary language can be a very clumsy tool for refined delicate purposes mathematics emerged as a special language in which basic concepts can be discussed with clarity and with precision, a language moreover capable of great beauty. Hence in introducing the idea of model building into the management situation one is making a break from a whole line of language and of thinking in management processes. Most of the managers with whom we deal are essentially non-scientific. I do not use this expression in the pejorative sense. The approach of the non-scientist to decision problems can be valid but there is, in this approach, a great deal of the cult of the amateur. For many years it has been thought possible to run large industrial concerns and government departments from deep leather armchairs by Socratic discourses, like a B.B.C. current affairs programme. Operational Research is a break from this tradition. The operational researchers have no experience, *per se*, of any situation to offer; only a belief in observation, classification, measurement and analysis.

A model, in other fields of science, provides an opportunity of experimenting with a real life situation. The first thing we have to ask in building a model is, what is the structure of the situation with which we are faced? By structure I mean the logical set of relationships between cause and effect. When we think of cause and effect, we have to cease thinking in the strict nineteenth century terms of a definite cause which inevitably leads to a given effect. We are not dealing with rigid deterministic situations. We are dealing with situations in which a set of causes can lead to a variety of effects. One of the changes in science in the last fifty years has been the recognition of patterns of probabilities. Consequently in our model building, when we deduce a logical set of relationships between cause and effect, we

are evolving a picture of a structure which involves probability linkages and it is the structure of the problem situations with which we are faced, which gives the common, cohesive link which runs throughout Operational Research.

Structure of Problems

Each one of us, if we enjoy our work, finds that our enjoyment reaches its peak and is particularly reflected in one or two facets of our job. The facet which intrigues and fascinates me about Operational Research is the way in which the structure of problems emerges. At the beginning, in every situation, in steel or in sugar, in coal or in confectionery, in textiles or in transport, the problem situation seems totally different. The feature is that as one studies the different problem-situations facing executives in these markedly different industries, then gradually from out of the fog of our lack of knowledge, emerges a structure of cause and probable effect from which we can plot a flow chart of the management situation. Every management situation resolves into a number of forms. The surface flesh of complexity of content disappears under examination and we have a 'skeleton' of causes and their probable effect.

Having evolved the basic form of the model, we have now to clothe this in quantity. This we do by an attack on the real live data available, frequently by appeal to statistical methods. We clothe the structure with number. We are now in a position to experiment with the real life situation in a translated form. The company, if this is what we are observing, can now go bankrupt on paper, which after all is by far the best way to go bankrupt. The army division, if this is our study, can suffer traumatic defeats on paper, which is the least painful way to be defeated. It is at this stage that the Operational Research worker has to ask what are the real objectives by which he judges the consequences of different courses of action as revealed by the manipulation of the model.

Earlier, when I defined what I meant by organizations with which an Operational Research worker has to deal, I introduced the idea of an objective and suggested that an organization has, either consciously or subconsciously, a set of goals towards which it is proceeding. It is attractive to assume that every organization is specifically and continuously conscious of these goals, that every member of its management, at every level, is constantly assessing alternative courses of action against these goals. Nothing could be further from the truth. There is an Arcadian simplicity in assuming that organizations, and in particular business organizations, exist only to maximize profit. I have never yet met a management situation in which the maximization of profit was the sole criterion of judgement. The slick rolling off the tongue of the phrase 'We exist to maximize our profits', betrays in the manager a

lack of clear thought about what the real objectives of his company are. Companies have many objectives, of which profit is a major one. The fundamental difficulty of the task facing the executive is that he has a number of separate objectives and that often these conflict. Even where they do not conflict, each objective is measured in different units and the performance of the organization is measured also in terms of these separate units. This means that it is very difficult for manager and Operational Research worker alike to evaluate alternative courses of action in terms of a single parameter on a scale of measurement which then will inevitably lead to an exact conclusion as to the best course of action. In some cases, to which I shall return shortly, it is possible to erect models which take cognisance only of a single objective and in these cases, provided adequate raw data are available, it is possible to derive models of a high degree of sophistication. But in general the greater the number of objectives and the greater the number of the units in which they are measured the more simple the form of model evolved is likely to be.

How then can we determine the objectives of an organization? We must remember that there are two parts to this statement. We can ask what the objectives are and we can also ask what they ought to be. It is no part of our task to accept organizational objectives as they appear to be. To find out what the objectives of an organization are, is rather like trying to find out what are the laws of a country such as ours, where the greater part of the laws by which we are governed are not Acts of Parliament as such, but rather decisions handed down by the courts which interpret the Acts of Parliament. We evaluate and understand the objectives of an organization by looking at the decisions handed down by management and deducing from these what the objectives are. Often this can lead to an immediate and conscious recasting of objectives by an organization. Perhaps one of the most important achievements of management consultants in business, is this cold look at the implications of company's decision making.

Often, we only become fully conscious of what the objectives should be, at the time when the study is completed. There is no simple algebraic way of approaching these problems. We do not start with an objective function on the right hand side of which we have the controllable and uncontrollable variables with which we are faced and relate these to a clearly defined objective on the left hand side and hence build up the model. Operational Research, like all scientific research, is not logical. It does not proceed in deductive stages from one step to the next. Operational Research, like all scientific research, has a large element of art associated with it. Although we may write up our research in what looks like a logical manner, the way it is carried out does not bear much relation to the way we write it up. Stating the objectives is one of the most difficult phases of an O.R. study

and in order to define them we have thoroughly to understand the way the organization works.

Having managed, in some way or other, to understand the objectives of an organization, having managed to build up logically this network of cause and probable effect which we call the model , we now have to look at the results which are being achieved and, bearing in mind the subject of this lecture, we have to see where future developments are likely to lie.

Models and Computers

I referred just now to the fact that the fewer the objectives and the greater the possibility of full measurement, both of performance and of objectives, the more highly sophisticated is likely to be the model which is built. It is probably the case that in the oil industry we find the most highly developed model building of the purely mathematical kind. The methods of linear programming, which originally stemmed from problems of economists in American oil companies, have received widespread application throughout industry but it is still in petroleum that they have been most highly developed. Many of our oil companies use these methods for building models, in order to plan the output of refineries, the relationship of production with market requirements, to deal with shipping problems and oil exploration. Probably the leading company in this field is British Petroleum which has evolved models of the activities of the company consisting of 700 equations in over 1,000 unknowns. Such models cannot be evaluated other than on the largest computers and the company has evolved and spear-headed the development of very large scale computing facilities for the important work involved in the solution of these problems. They have taken the ordinary continuous linear programming algebra and extended it into non-continuous cases and also into the non-linear field. In all this work the task of the Operational Research worker has been to act as a sophisticated link between senior management and computer people. They have managed to take the structure of the refinery problem and to cast it in the standard forms on which the computer can operate. As this work has evolved it has become more and more possible for the Operational Research worker, having stated the standard problems and evolved the standard language, to fade out of the picture and to leave Company Management to cast their problems in the standard language of the computer and for the problem to feed directly from them into the computer. Obviously there are dangers involved in removing a human intelligence from this link-up stage but it does take one a large step forward into the possibilities of complete automation of decision-making in refinery situations and even to computers developing their own programmes and hence eliminating the computer programmer.

Models of this type can only be solved if the computer can handle the

algebra. In probabilistic situations, algebra is too fragile a tool and some groups, particularly the United Steel Company, have used simulation approaches to build models of production processes incorporating a high degree of variability which makes possible experimental methods akin to those of the laboratory scientist. My own belief is that the development of simulation, with its opportunity of building understanding through experience, is the most important area of all for the O.R. worker. For simulation is the bridge which links us with the classical scientist.

It is tempting to look on model building of the British Petroleum and United Steel type as something which is indigenous to large organizations. This is not so. Medium sized companies have developed models of their activities which manage to integrate the whole of the problem of the company from the buying of raw material on varying price markets, to the rather complex problem of production scheduling with shared facilities, to the finished goods stocks and finally to the whole problem of marketing and advertising at the other end of the operation. This gives management, particularly the top management of the company, an opportunity of reviewing in quantitative fashion the operation of the whole company rather than the separate parts into which the normal organizational chart divides it, for the typical process of management is to cut complex problems down to size.

Cutting Problems Down to Size

All the problems with which we deal in life are cut down to a size in which they are manageable. This involves two stages of thinking. We have, first of all to state what are the relevant factors in the real life situation. Mathematically we are producing a many-one transformation in which the many factors of real life are translated into single factors of the terms of which we deal with them. This is the way, we each one of us, run our day to day life, because we cannot deal with a multiplicity of factors. Hence we tend to think of the 50,000,000 people living in France, in terms of the personality of General De Gaulle. We think of the economic health of our nation in terms of at most three different indices of performance. Such translations are common features of our life. They are common features also of the way in which the business operates but the way in which this translation occurs is fundamental to good business and good management alike. The second task with which the manager has to deal is not only the translation from the multiplicity of real life into a number of factors with which it is possible for his brain to deal, but he also, by delegation, has to enable the business to be run on a day to day basis. The easy way of delegating responsibility is to divide operations functionally. Hence we have marketing directors, production directors, personnel directors, industrial relations, finance and purchasing directors all dealing with separate vertical slices of

the company's organization and carrying out their own jobs by vertical delegation. In cutting problems down to size by vertical slices we are imposing a measure of inefficiency on the way companies operate.

The approach of the scientist is quite different. He deliberately brings in interactions and interplay of different features which are channelled departmentally in the normal company organization model. He has to carry out his many/one transform and the number of factors with which management can deal through the vertical linkages imposed on companies. We have, as far as we can, to build up to the *whole system* of the organizations with which we are dealing. In our recognition of this need we owe a debt to the cyberneticians who by constantly banging this theme into our ears have led us away from the 'within department studies' to which Operational Research seemed committed fifteen years ago, and let us to consider instead the problems of the organization as a whole.

So far I have been dealing with the situations in which, by implication, we have complete access to data, to quantitative analysis, and are able to evolve sophisticated and complex models. The word computer has come up again and again in what I have been saying and you may be thinking that the computer and Operational Research go together like Marks and Spencer. This is not so and it cannot be too often repeated that a computer is neither necessary nor sufficient for good quality O.R. Indeed a great danger of a University Operational Research department is that it may become so theoretically oriented, so conscious of the ritual algebraic dances round the point of decision with which so much of Operational Research seems to be occupied, that we neglect the fundamental feature of O.R., which is that it is a problem solving discipline.

The two sorts of problems with which we have had greatest success have been those in which, as I have said, we have a great deal of numerical data available, where we are fully conscious of what the objectives are, we can measure performance relative to these objectives, and hence we can derive quite sophisticated mathematical models. But we must not imagine that most of the problems which arise in industry have a surplus of data associated with them. In fact, one finds that to a large extent management is driving in a fog. There is a horrible shortage of real quantification available to managers for the problems with which they deal. In most research situations we have to set up special machinery for collecting data in order to guide us in our model building as the real life data we require are not there without special effort being made to collect them. This remark particularly applies to the spurious sort of data which the accountant so often produces. Let me make it quite clear that one of the best assets a company can have is a real, live, up-to-date, modern minded accountant. By this I mean an accountant who is aware of probability and variability, who is aware of the

problems of forecasting for the future, but who is also aware that a great deal of the basic accountant's training consists of learning routines by rote. I can count on the fingers of one hand, the occasions in which accounting data has been of use and has been able to be incorporated as such into research studies with which I have been associated. So often the conventional treatment of overheads, allocation of revenue and costs, which can be treated in so many different ways quite conventionally by the accountant, irretrievably forces a management decision one way or another. In fact if you have a pet scheme to get through in a company one of your best courses of action is to become friends with the accountant.

But even when we appear to have the information available, we are still left with a large number of situations in which no accurate data at all appear to be available. The problems of marketing, of the operation of sales forces, of the effects of advertising on sales, are those to which Lancaster University, through the development of its Marketing department, is committed. It is a curious feature of unsuccessful companies, that they all regard purchasing and production as honourable occupations suitable for a gentleman, but selling as something for bounders. The problems of Marketing, and here I speak personally, have caused me more headaches and mental stretching than any others I tackle and are clearly worthy of serious scientific study. In these areas we are groping for measures of effectiveness relevant to the objectives of a company. We will find always that the first time we manage to evolve a measure of performance relevant to an objective, not just in marketing but in other fields also, we have obtained a bigger pay off than anything else we shall ever do. It is not solely a question of measuring cost or measuring performance in some absolute way. Assessing a probability in a rational way gives us a large increase in efficiency. Such measures of probability when evolved have been used to show commodity buyers how to deal with forecast price movements in a price market in order to determine what should be their level of stocks at any current time. Measures of probability have enabled oil companies to determine how to spread out money in bidding for tracts of land in an auction so as to maximize their expected oil yield in terms of a given amount of money expended on bids. Determination of measures of probability has enabled textile firms continuously to up-date their merchandise so as to minimize the chance of being left with out-of-fashion goods on hand.

When one thinks of the use that has been made of the derivation of probabilities in terms of women's fashion sales one realizes that the Operational Research worker is not restricted to dealing with the hard deterministic features of life. But you may rightly be asking about an important boundary of O.R. For all I have been dealing with so far comprises only four of the basic variables with which executives have to content — machines,

markets, materials and money. What of the dominant fifth, what of man himself and all his works. How do these fit in?

The Human Factor

In our studies we come again and again to the boundary of what we loosely call, the human factor. Inside each one of us there is a Luddite straining to get out. Whereas we feel that measurement, classification and analysis are very good for the inanimate, we resist the feeling that we, ourselves, should be the subject of measurement, analysis and classification. Can the infinite variety of the human soul and the human spirit we represented by a few impulses in an electronic computer? Is not the behaviour of the individual human so unpredictable that when we come to this limit, we must draw back and leave men out of our models.

We must remember that science itself is dealing fundamentally with the behaviour of the unknown, irrational and unpredictable. For example I know that if I have a kettle of water at 100 degrees centigrade, it will be boiling. I know also in terms of the amount of heat I am applying to the kettle of water in the form of the gas underneath it, the rate at which molecules of water will be converted to molecules of steam. This I know and can predict exactly. But when I look at the separate molecules of water, each of which is at 100 degrees centigrade, I have no way of predicting which will be the next molecule of water to transform into steam. Similarly, the physicist will tell us the half life of a radioactive compound, he can forecast how many molecules will be transformed in any one hour. But he cannot say which molecules.

We can deal with humans in the mass in the same way that we deal with molecules. Given the ages of each person in the audience here this evening an insurance actuary could forecast with a fair degree of accuracy, how many people here will have died by exactly one year from this moment. He would not be able to walk through the audience and place his hand on the shoulder of each one who will have died by 7.45 p.m. on 12th May 1966 but he will be able to forecast how many. In the same way, for example, the Operational Research worker can study the problems of recruiting labour, the problems of accidents and absenteeism, general measures of morale and can derive group measures of performance. What we are still groping for is to derive measures of the effectiveness of group structures and organizations as such. It is easy to draw an organization chart and to give advice on the layout of organizations and the channel of communication, authority and discipline. But organizations consist of groups of people linked in different ways, and what we have still to be able to derive are quantitative measures of the effectiveness of an organizational structure. And so far as the individual himself is concerned we still have to feel and

grope for measures of happiness, health and well-being, for it is after all to the happiness of the individual members of the community that the state must be chiefly committed. It is in the understanding of the individual and in measures of the individual's performance and welfare that we shall lean ever increasingly on the social scientist for assistance but we would still, pace the physicist, be content with measures of group performance and even though we feel that at the basis of all our work is the fundamental uncertainty of the individual. Nevertheless we will not draw back from measures of individuals and of groups, and feel that because of this fundamental uncertainty, our results are invalid.

Centralization and Decentralization

In the last 50 years individuals at the centre of organizations have felt increasingly incapable of dealing in a rational way with the growing complex of information which is available and this has led to decentralization. We shall shortly find that this process will be drastically reversed. One of the consequences of the increasing development in organization of Operational Research and large scale data processing is going to be a move to centralization. This obviously carries with it dangers, but when leaders of industry find that they are capable of digesting whole masses of data, and, through electronic control processes, of dealing with extended operations, then the reason for decentralization and delegation, which was basically technological, will no longer obtain. I think, therefore, that one inevitable result of the development of measurement, of analysis and all the other fruits of Operational Research will be an increasing power at the centre of organizations.

As a parallel we may observe that the history of evolution shows that as organisms develop their nervous system, their internal system of communication and control, then the central co-ordinator, e.g. the head, emerges first as a dominant centre and finally as the one essential part that controls the whole down to the last detail. Companies and industry generally must be very careful in realizing that in subtracting power from the individual who previously possessed it, they are dealing a blow to his morale. It is necessary for the individual in an organization to feel that his capabilities are being fully realized and developed. If management finds itself in the soul-destroying monotony of routine jobs carried out at less than natural capacity, then executives will suffer from the same boredom with which the worker is often faced and perhaps we will find management unrest in the same way, that in many industries one has labour unrest springing directly from boredom. At the same time, it is tempting to assume that the effect of O.R. and of vastly improved communications and control, will be to make the task of the central manager more easy. In fact it will be much more difficult because the central manager will be forced into considering

in depth and detail the principles which will underlie all decision making.

But the other consequences of measurement and of analysis may well be felt at government itself. The big change in politics in the last 15 years has been the increasing knowledge by governments of the general state of opinion in a country. We are familiar with Gallup Polls, and it is fashionable to cheer when they are wrong. We must be aware that the Gallup Poll gives a far better idea of the state of opinion at any time than does hunch or intuition. If a government in power can choose its own time for going to the country in a general election, i.e. it is not limited by the size of its majority or by time running out, the development of opinion polls means that the odds are always on the government winning an election. This leads to two results. Firstly governments will tend to stay in power for longer periods. The second result is that whereas when a new government wins a general election it has won an election at the time of the choosing of its opponents, at the next general election, the first one in the life of a new government, the odds are that the new government will actually increase its majority from a previous general election. So we must not be surprised if the second parliament in the lifetime of a government has a larger majority than the first and we must expect governments to remain in office for longer. Whether this is a good thing or not depends perhaps on the party one happens to support and also on one's general view of the function of government. Neither of these points are for me to comment on this evening, but they do illustrate that the development of knowledge of measurement and the general development of model building, are going to lead to an increasing power at the centre of organizations, whether the organizations concerned are industry or government itself. This does not mean that we should draw back from model building, it does not mean we must draw back from trying to understand what is happening. What it does mean is that we must consider very carefully what other actions industry or government should take to ensure the well-being of people in these centralized power complexes to which we are inevitably moving. I think we have failed so far to understand the change that is going to take place and to understand also that if, as we must be, we are ultimately committed above all else to the happiness of the individuals of whom society is composed, then we must give more thought to understanding the place of the individual in the power centralized societies to which we shall move.

In finishing let me make a declaration of faith. I referred earlier to the fog which seems to be endemic in all industrial and government decision making. The world at large is, as Joxer put it, 'in a terrible state of chassis'. In every problem we seem to be overwhelmed by noise, uncertainty, ambiguity and chaos. How are we to regard the world? Is it a world which is anarchic and chaotic by nature and is the task of the O.R. scientist to impose order on

this world by writ of force? Are we all at the blind sport of some alien sower of discord? Or is the world fundamentally orderly and are there, underneath all the noise, patterns and relationships? Is life reasonable at basis and has man's contribution been to add chaos by his blundering and lack of understanding?

I can only accept this latter view. The world in which we live makes sense, it makes common sense. But common sense is not what we put there, it is what we find there. Pattern, order and common sense are what the physicist finds at the heart of the atom. Pattern, order and common sense are what the botanist finds under his microscope. Pattern order and common sense are what the astronomer finds in the reaches of the universe.

We are not as skilled in our craft, we have not the traditions and experience of our colleagues in other sciences, but this sense, pattern and order are what we find underlying the situations for which we construct our halting, simple, hesitant models in the complex situations of industry, commerce and government with which we deal.